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Fine Solids Removal Following Combined Chemical-Trickling Filter Treatment

North Carolina Univ. at Chapel Hill

Prepared for

Municipal Environmental Research Lab.
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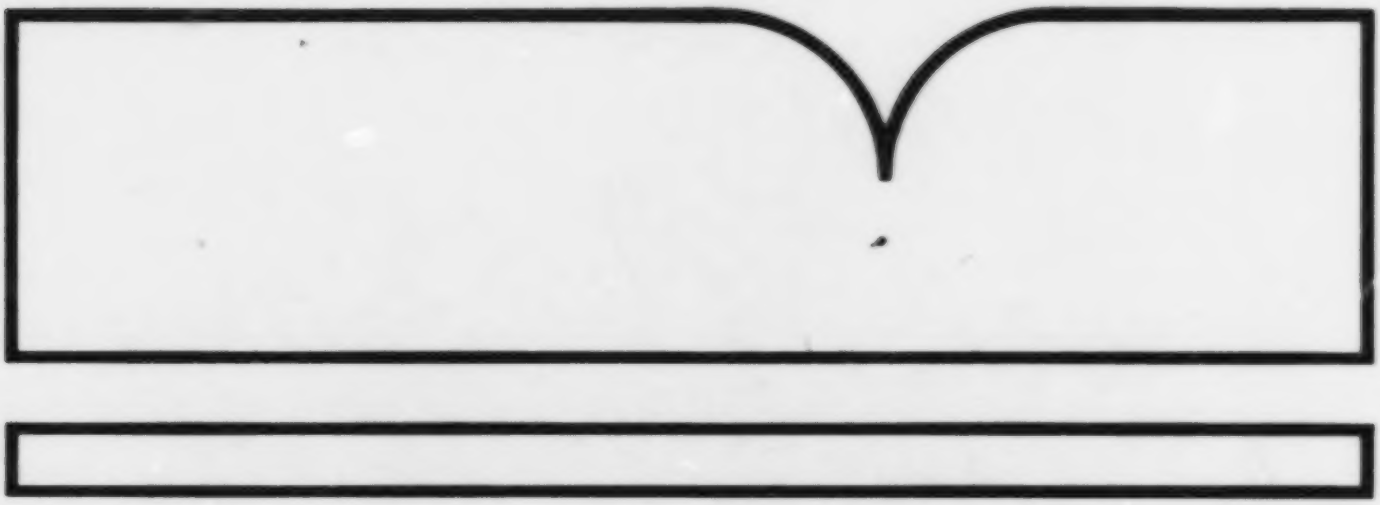

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16. ABSTRACT

This research project was designed to evaluate the effectiveness of settling ponds and several types of granular media filters for removing residual fine solids from the effluent of a conventional, high-rate, rock media trickling filter plant when alum is applied ahead of secondary clarification. Two pilot settling ponds, one covered and one open, were operated at detention times ranging from 8 to 30 hr. Two pilot granular media filters were operated at filtration rates ranging from 1.0 to 2.0 l/sec/m^2 (1.5 to 3.0 gpm/ft^2). The filters were operated in both downflow and upflow modes, with various media used in each operational mode.

The pilot settling ponds did not perform as expected. Anaerobic conditions, which developed in the settled sludge, disrupted the floc structure and resuspended previously settled solids. Very modest improvement in final effluent quality, generally less than 25 percent, was observed.

The two filters, when operating in a downflow mode with two different configurations of anthracite and sand media, proved about equal in performance, achieving 65-85 percent incremental removals of suspended solids. Upflow filter operation produced a slightly lower effluent quality but resulted in lower rates of headloss buildup and substantially longer filter runs.

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FINE SOLIDS REMOVAL FOLLOWING COMBINED CHEMICAL-TRICKLING FILTER TREATMENT

by

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This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the Anerican people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

The studies described here were conducted to evaluate techniques for removing fine solids carryover from a full-scale trickling filter facility dosed with aluminum sulfate (alum). Alum has been shown in other work to be compatible with the trickling filter process for precipitating phosphorus and coagulating unsettled biological floc. This report documents the potential of several tertiary options for additonal solids removal when final clarifier loadings become too high to realize maximum benefits of combined chemical-trickling filter treatment without supplemental upgrading.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

The addition of alum ahead of the final clarification stage of the trickling filter process has been observed to improve effluent quality. Soluble phosphorus is precipitated, and fine biological floc is entrained in the alum floc matrix and thereby rendered settleable. One of the important factors affecting the removal efficiency obtained with alum addition is the hydraulic loading applied to the final clarifier. When the surface overflow rate is above 24.4 $m^3/day/m^2$ (600 gpd/ft^2), significant amounts of fine alum floc, biological solids, and precipitated phosphorus are carried over with the clarifier effluent.

This research project was designed to evaluate the effectiveness of two methods of fine solids removal for possible application following normal clarification when alum is applied ahead of the clarification stage. The methods investigated were: 1) fine solids settling ponds and 2) various types of granular media filters.

Two pilot settling ponds, one covered and one open, were operated at experimental detention times ranging from 8 to 30 hr. In addition, two pilot granular media filters were operated at filtration rates ranging from 88 to 176 $m^3/day/m^2$ (1.5 to 3.0 gpm/ft^2). The filters were operated in both the normal downflow and upflow modes. Various filter media were used in each operational mode.

The pilot settling ponds did not perform as expected. Anaerobic conditions which developed in the settled sludge disrupted the floc structure with consequent resuspension of the previously settled solids. Algal growth in the uncovered pond was a problem.

The use of pilot fine solids settling ponds following combined alum/trickling filter treatment resulted in a very modest improvement in final effluent quality. The application of fine solids settling ponds appears to be inappropriate where more than a 25 percent improvement in effluent quality is required.

The two filters, when operating in the downflow mode with two different configurations of anthracite and sand media, proved about equal in performance. Both filters performed fairly well when the main plant effluent was good. Poor plant effluent (filter influent) resulted in short runs, rapid buildup of headloss, and low quality filter effluent.

Upflow filters produced a slightly lower effluent quality than the downflow models. The upflow mode of operation, however, did result in lower

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rates of headloss buildup; substantially longer filter runs proved feasible.

This report was submitted in fulfillment of Contract No. 68-03-0225 by the University of North Carolina under the sponsorship of the U.S. Environmental Protection Agency. The report covers the experimental period of September 10, 1973, through March 6, 1975.

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The pilot plants were constructed by George Burns. Some of the experimental work with granular media filters was conducted by Philip Braswell, a graduate student in the Department of Environmental Sciences and Engineering.

The manuscript was typed by Mrs. Delores E. Plummer.

SECTION 1

INTRODUCTION

REASON FOR THE STUDY

Significant carryover of fine alum floc solids was observed in final effluent during earlier plant-scale studies of alum addition to the final clarifier of a high-rate trickling filter train of the Chapel Hill, North Carolina wastewater treatment plant (1). Data generated during these studies revealed that although phosphorus insolubilization is relatively unaffected, overall alum treatment effectiveness in terms of suspended solids and precipitated phosphorus floc capture becomes increasingly limited as the hydraulic loading on the final clarifier increases. The effect of final clarifier overflow rate on effluent total suspended solids (TSS) and total phosphorus as recorded in the previous project is illustrated in Figures 1 and 2, respectively.

Simple laboratory experiments indicated that additional physical separation of suspended solids, either by means of fine solids settling ponds or with granular media filters, held potential for producing significantly improved final effluent quality when applying alum at wastewater treatment plants equipped with trickling filters. Follow-up pilot plant evaluations were conducted on sidestreams of Chapel Hill plant effluent to compare these two methods of upgrading alum-flocculated trickling filter effluent. The results of those follow-up evaluations are the subject of this report.

PROJECT SCOPE

Solids escaping the final clarifier during plant-scale tests of alum treatment were mostly fine alum floc and would reform and settle in laboratory jars. It was anticipated that these solids would settle in a pond and would form a relatively stable sludge layer as in a water treatment plant with non-mechanical settling tanks. These accumulated solids could then be removed from the ponds at 3-6 mo intervals.

Two outdoor pilot settling ponds were constructed, one covered and one uncovered. They were designed to operate at various hydraulic detention times ranging from 8 to 30 hr. Observations were taken on pond influent (plant effluent) and effluent quality. Monitoring plans included measuring sludge accumulation on the pond bottoms.

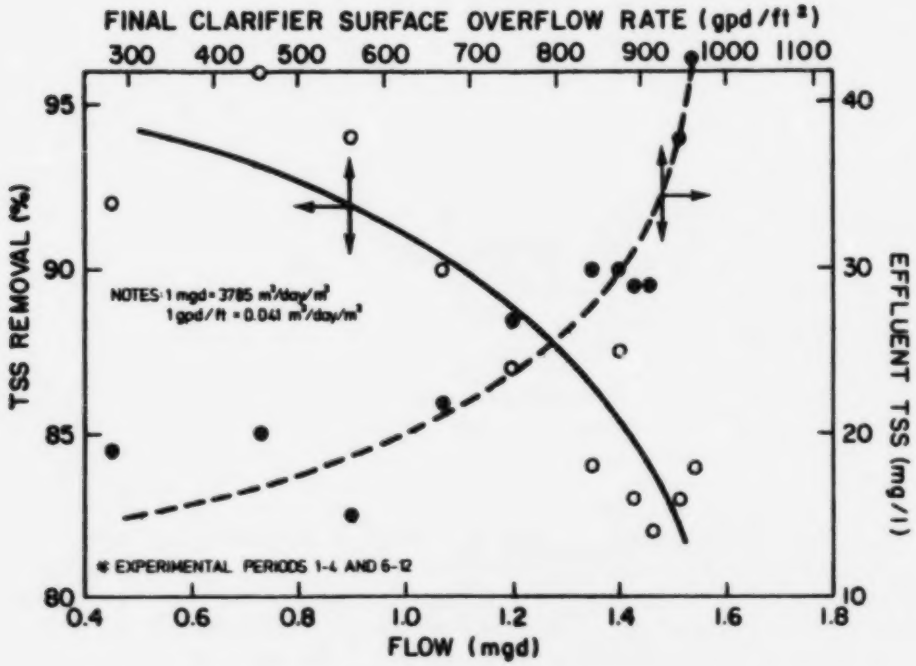

FIGURE 1. Suspended solids removal as a function of flow and final clarifier overflow rate for initial project (1).*

A pair of granular media filters were fabricated and installed inside the University of North Carolina's pilot research building on the grounds of the Chapel Hill plant. The filters were designed to explore the effect of different filtration media, varying filtration rates, and operating in two different filtration modes (upflow and conventional downflow).

Two downflow media configurations were evaluated: a dual media anthracite over sand system and a four media system of fine anthracite over coarse anthracite over sand over garnet. Two upflow media configurations were also studied. One upflow unit employed three grades of granite chips topped with sand; the other used just two grades of granite chips with no sand topping.

During this investigation, the Chapel Hill plant was operated with an average dosage of 198 mg/ℓ of alum (as $Al_2(SO_4)_3 \cdot 14.3\ H_2O$) applied to one-half the plant, i.e., at the influent to the final clarifier of one of the two trickling filter trains. The clarifier overflow rate ranged from 9.7 to 100.7 $m^3/day/m^2$ (239 to 2472 gpd/ft^2). The alum treated trickling filter effluent passed through this single clarifier, and the effluent from the clarifier was used to supply influent to both the pilot settling ponds and the pilot filters.

Experimental studies were initiated in mid-September 1973. Work was terminated in July 1974 on the filters and in March 1975 on the ponds.

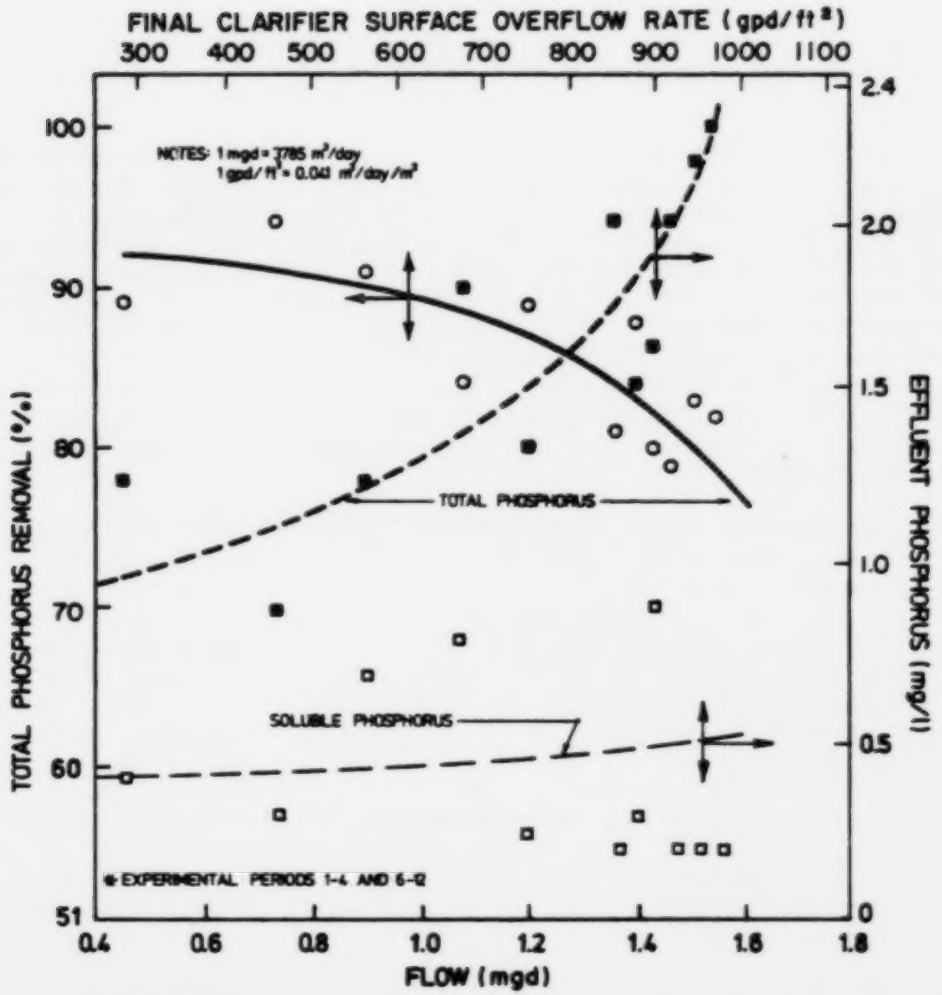

FIGURE 2. Phosphorus removal as a function of flow and final clarifier overflow rate for initial project (1).*

SECTION 2

CONCLUSIONS

The settling ponds did not function as expected. The removal of BOD, suspended solids, and phosphorus in the ponds was lower than expected and erratic. Pond effectiveness appeared unrelated to detention time in the range of 8 to 30 hr. Anaerobic conditions developed in the sludge accumulating on the pond bottoms. The floc structure then broke up, and a large portion of the previously settled solids was resuspended. Also, algal growth in the uncovered pond was a nuisance and resulted in a fairly heavy scum layer of dead algal cells at the surface of the pond. On the basis of data obtained during this investigation, the use of settling ponds following trickling filter plants in which alum is applied will provide a modest improvement in final effluent quality; however, their performance is not reliable or predictable.

The two downflow filter configurations tested proved approximately equal in performance. Both filters performed fairly well when the main plant effluent was good. When the influent to the pilot downflow filters was of lesser quality, i.e., BOD_5 of approximately 20 mg/ℓ and TSS of approximately 30 mg/ℓ, the removal of both BOD_5 and TSS ranged from 55 to 72 percent. Percent removal was not affected by filtration rate. When filter influent was of better quality, the percentage BOD_5 removal was lower, probably indicating a large fraction of the BOD_5 was in soluble form; however, the removal of total suspended solids was not significantly effected. Poor plant effluent (pilot filter influent) resulted in high rates of headloss buildup and short filter runs. The rate of headloss buildup was, of course, greatest at the highest filtration rates. (The rate of headloss buildup increases in direct proportion to filtration rate when filtering clean water). The rate of headloss buildup was also affected by the quantity and quality of suspended solids in the filter influent.

In comparing a conventional downflow media configuration with two upflow configurations, both upflow configurations proved slightly less effective than the downflow configuration with regard to effluent quality. However, the rate of headloss buildup in the upflow filters was less than half that of downflow models. Prototype upflow filters should be capable of much longer runs than downflow models. During this investigation, in a period when personnel were available for round-the-clock operation (5/28/74-6/4/74 - see Table 6), the upflow filter operated up to three times longer than the downflow filter. The second upflow configuration which consisted of generally coarser media and greater media depth than the first upflow model proved simpler to operate as it was not prone to media separation during filtration.

SECTION 3

RECOMMENDATIONS

The application of fine solid ponds following combined alum-trickling filter treatment results in a modest improvement in final effluent quality. Such units should not be used in cases where more than a 25 percent improvement in effluent quality is required.

Additional work should be undertaken to explore the potential of coarse media upflow filtration for tertiary solids removal at wastewater treatment plants utilizating chemical treatment.

SECTION 4

EXPERIMENTAL PROGRAM

EQUIPMENT AND METHOD OF OPERATION - PONDS

The pilot settling ponds consisted of two steel tanks fabricated of 4.8-mm (3/16-in.) plate, 3.7 m (12.0 ft) in diameter with side wall height sufficient to permit a water depth of 2.1 m (7.0 ft). One tank was covered with black plastic sheeting supported on an angle iron framework and chicken-wire. The other pond was not covered. This was done to study the effect of the presence and absence of natural light on algal growth in the ponds.

Influent flow to the pilot ponds (and granular media filters) was supplied by a self-priming centrifugal pump mounted above the effluent channel of the main plant final clarifier. Flow to each settling pond was controlled by means of a double weir box which divided the flow equally to each pond. The actual flow to each pond at any time was determined by the level in the head box. This level was adjusted by raising or lowering the head box overflow pipe. Diurnal flow variation was simulated using two solenoid operated valves controlled with a timer. In this way, two different rates of flow were obtained at different times of the day.

The head box and splitter are illustrated diagramatically in Figure 3. Figure 3 also illustrates how the flow rates obtained by sequenced operation of the solenoid valves compare with a typical diurnal fluctuation in main plant flow.

Figure 4 shows the general configuration of the two pilot settling ponds. A photograph of the ponds is presented in Figure 5.

The pilot ponds were operated at detention times of 8, 12, 16, 20, 24, and 30 hr. Overall flow rates were adjusted, as required to obtain the desired detention time, by raising or lowering the overflow level in the head box.

Since the ponds were operated continuously for fairly long periods of time, the flow-weighted plant effluent samples from that side of the plant receiving alum treatment were used for pond influent samples. The pond effluent sampling lines flowed continuously, under gravity, to a flow proportional sampler. Pre-set timers operated valves to divert small equal portions of pond effluent to sample containers in a refrigerated box. Intervals between operation of the diversion valves were inversely proportional to flow; therefore, flow-weighted,24-hr composite samples were obtained.

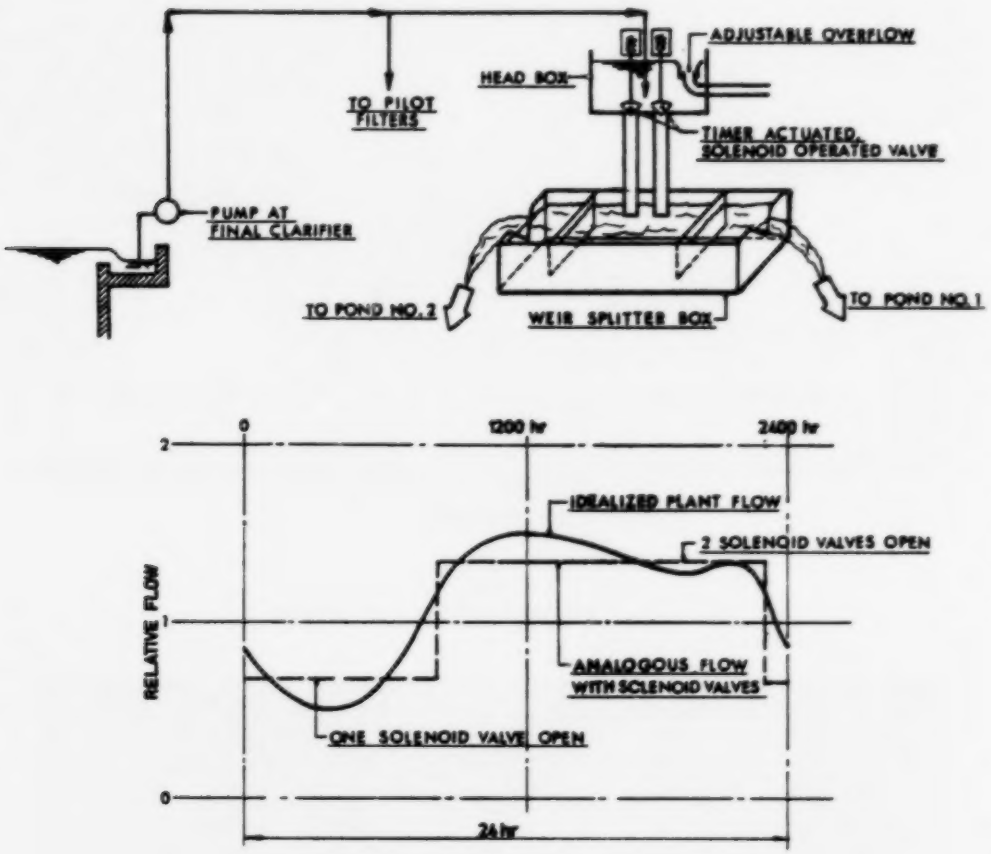

FIGURE 3. Pilot settling pond flow control system.

It was anticipated at the outset of the study that settled sludge samples could be drawn from the tank drain in the floor of each pilot settling unit. As will be discussed later, sludge did not consolidate sufficiently to permit representative sampling.

EQUIPMENT AND METHOD OF OPERATION - GRANULAR MEDIA FILTERS

The two pilot filters were constructed with clear lucite cylinders 3.0 m (10.0 ft) long with internal diameters of 29.2 cm (11½ in.). Each filter had a false bottom made of steel plate drilled with 44 equally spaced 4.8-mm (3/16-in.) diameter holes. The false bottom was fitted between flanges with gaskets. Filtered water collected in the filter bottom, which consisted of a flanged steel cone with the same large diameter as the filter shell. A general drawing of the arrangement of the two filters and appurtenances is shown in Figure 6.

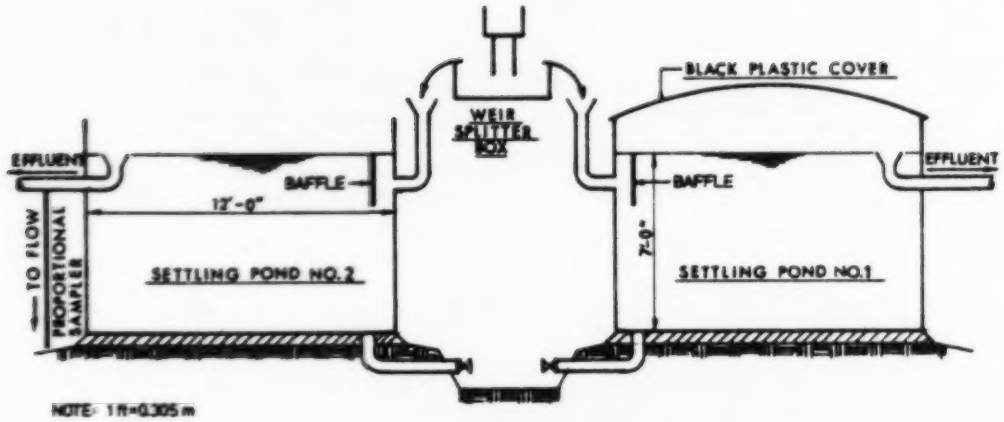

FIGURE 4. Pilot settling pond arrangement.

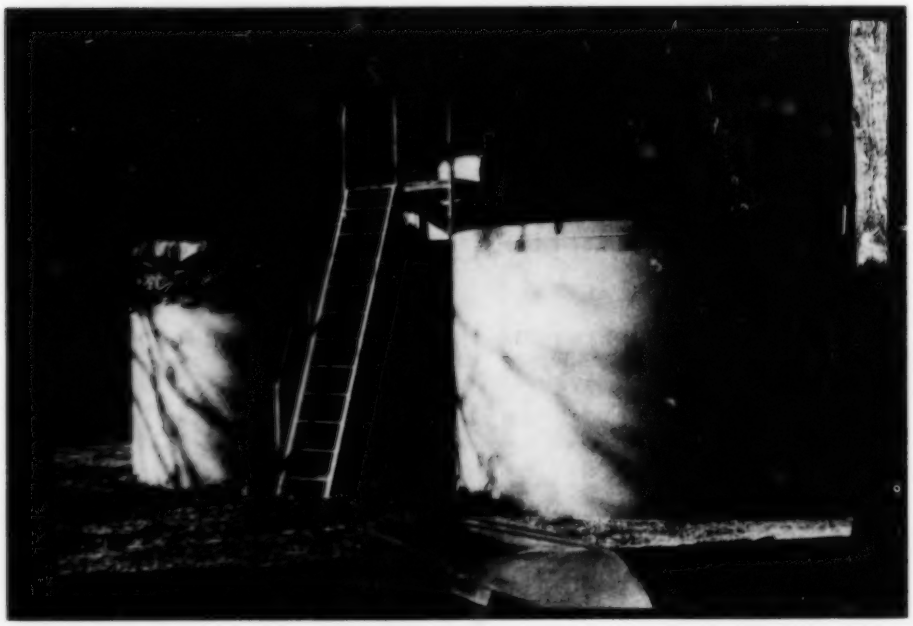

FIGURE 5. Photograph of pilot settling ponds.

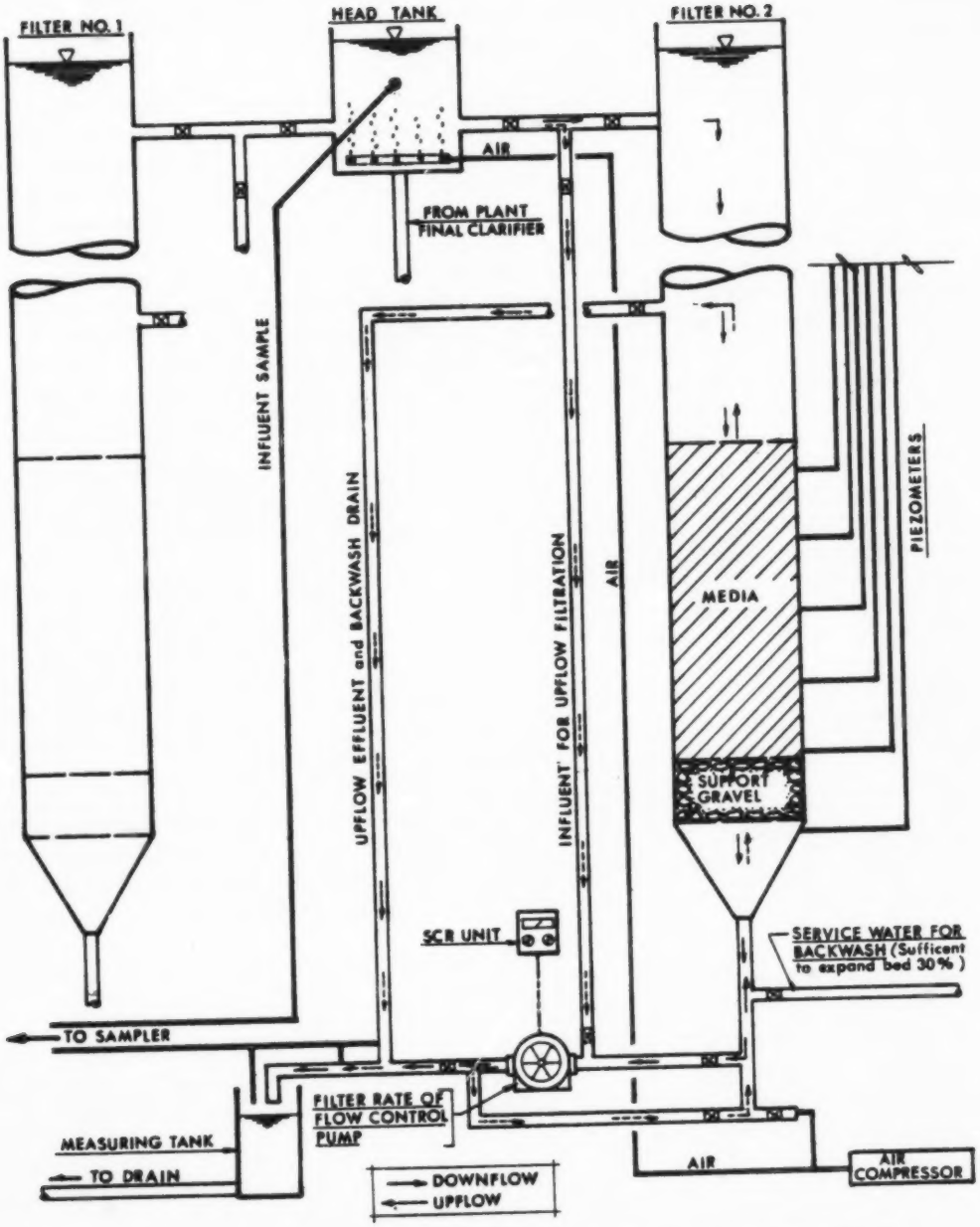

FIGURE 6. General arrangement of pilot granular media filters.

Influent for the filters (plant effluent) was pumped to a head tank which was maintained in a completely mixed state with air mixing. The same mixed effluent flowed to each filter. The two filter units treated the amount of water discharged by the individual filter control pumps. These pumps acted as effluent pumps when the filters were operated in the downflow mode and as feed pumps when operating in the upflow mode.

The filter pumps, which also functioned as rate controllers, consisted of Jabsco, flexible rotor, positive displacement pumps with direct current motors controlled with silicon rectifers (SCR units), which permitted complete variable speeds from the stall speed of the motor (about 50 rpm) to the maximum speed of the motor (1,750 rpm). The pump discharge rate was measured for various control settings and a calibration curve was developed. The desired filtration rate was set at the beginning of a run and checked by timed volumetric measurements. The rate was checked several times during each filter run. This system was found to be very reliable. When operating in the downflow mode, influent from the head tank flowed through the filter to the control pump and thence to discharge. In the upflow mode, water flowed from the head tank to the control pump and thence upward through the filter.

A backwash rate of 8.8 to 10.2 $\ell/sec/m^2$ (13 to 15 gpm/ft^2) proved to be sufficient to expand downflow media A and B and upflow media C at least 20 percent. Approximately 10 min of backwash proved sufficient to clean the filters. In backwashing, water alone did not prove as effective as air scour followed by water. As shown in Figure 6, an air scour system was provided. In backwashing upflow media D, it was not possible to suspend the coarse media in the bottom layers of the filter with the amount of service water available. It was, however, possible to effectively clean the filter with a combination of hydraulic backwash and air scour. Approximately 2 min of combined air scour and low rate hydraulic backwash followed by 8 to 10 min of hydraulic backwash (without air) was sufficient to clean the filter.

Filter influent samples were obtained automatically from the head box at regular time intervals. Filter effluent samples were also obtained at regular time intervals from the filter discharge. Samples were composited over the length of the filter run and stored in a refrigerated box.

Headloss buildup during filter runs was observed by means of piezometer tubes installed in each filter.

In general, the pilot filters functioned well. They were easy to operate and backwash. Regardless of the success or failure of any particular experimental program, these filters would have been excellent teaching units.

SECTION 5

OPERATION AND PERFORMANCE

SETTLING PONDS

The data obtained during the settling pond experiments as summarized in Table 1 followed no consistent pattern. The best removal efficiencies were obtained at a 12-hr detention period, but relatively poor removal efficiencies were obtained at all other detention periods. During some experimental periods, the covered pond performed better than the uncovered; in other periods, the opposite was observed. The best performance for both the covered and uncovered ponds, i.e., during the 12-hr detention period, was during the warmest weather. Table 2 compares average influent and effluent parameter concentrations for the various detention periods investigated.

Little sludge was found to accumulate on the bottom of either the covered or uncovered ponds. The TSS in the pond underdrain varied from a high of 108 mg/ℓ to a low of 35 mg/ℓ. Dissolved oxygen (D.O.) analyses conducted at various liquid depths in the ponds showed a range of concentrations of between 6 and 8 mg/ℓ at the surface to less than a detectible concentration in the bottom 0.6 m (2 ft); the D.O. concentration decreased more rapidly with depth in the covered tank. It is believed that anoxic conditions in the lower level of the tanks resulted in anaerobic decomposition of solids and that this process destroyed the physical structure of the alum floc, dispersing fine solids throughout the tank. It is further believed that the overall removal of BOD, TSS, and other parameters in the ponds was a result of biological conversion rather than physical separation by settling.

During all warm weather periods, the uncovered pond was blanketed with an algal scum and the effluent from this pond had a pale green color. These conditions did not develop in the covered pond. Significantly higher D.O. concentrations were observed in the uncovered pond, and measurable concentrations persisted to greater depths within the pond. Neither the algae nor the coincident higher D.O. levels in the uncovered tank resulted in any significant difference in performance as compared with the covered tank.

TABLE 1. PILOT SETTLING POND DATA

Parameter mg/ℓ	No. of Samples	Pond Influent	Pond Effluent No. 1 cov'd	Pond Effluent No. 2	% Removal No. 1 cov'd	% Removal No. 2
		8-hr Detention 1/30/75 - 3/6/75				
BOD	21	41	--	39	--	5
TOC	19	44	--	39	--	11
TSS	22	70	--	60	--	14
TVSS	20	51	--	44	--	14
NO_2-N + NO_3-N	21	0.5	--	0.5	--	0
NH_4-N	21	21.7	--	22.5		(4)
Total PO_4-P	22	6.2	--	6.4	--	(3)
Filtered PO_4-P	22	2.7	--	3.1	--	(15)
Turbidity (JTU)	21	34	--	28	--	18
		12-hr Detention 7/10/74 - 10/8/74				
BOD	11	28	14	15	50	46
TOC	15	39	21	24	46	38
TSS	15	68	32	35	53	49
TVSS	15	40	23	22	43	45
NO_2-N + NO_3-N	13	2.7	1.0	1.1	63	59
NH_4-N	13	20.4	20.4	20.6	0	(1)
Total PO_4-P	14	6.2	2.3	2.5	63	60
Filtered PO_4-P	14	1.1	0.6	0.5	45	55
Turbidity (JTU)	15	33	13	15	61	55
TSS in Settled Sludge from Pond Drains (mg/ℓ)	6	--	84	108		

(continued on next page)

TABLE 1.(continued)

Parameter mg/ℓ	No. of Samples	Pond Influent	Pond Effluent No. 1 cov'd	Pond Effluent No. 2	% Removal No. 1 cov'd	% Removal No. 2
		16-hr Detention 4/3/74 - 6/10/74				
BOD	19	17	12	12	29	29
TOC	24	18	15	18	17	0
TSS	24	34	35	31	--	9
TVSS	23	22	21	19	5	14
NO_2-N + NO_3-N	24	1.2	0.5	0.7	58	42
NH_4-N	24	20.7	19.3	18.9	7	9
Total PO_4-P	24	2.2	1.6	1.7	27	23
Filtered PO_4-P	18	0.9	0.5	0.5	44	44
Turbidity (JTU)	20	17	13	14	24	18
TSS in Settled Sludge from Pond Drains (mg/ℓ)	8	--	44	63		
		20-hr Detention 2/13/74 - 3/10/74				
BOD	14	35	20	22	43	37
TOC	14	34	30	33	12	3
TSS	15	54	43	46	20	15
TVSS	15	27	26	26	4	4
NO_2-N + NO_3-N	15	2.2	0.5	0.7	77	68
NH_4-N	15	23.7	26.3	25.7	(11)	(8)
Total PO_4-P	15	4.4	3.3	4.0	25	9
Filtered PO_4-P	15	0.9	0.5	0.5	44	44
Turbidity (JTU)	14	23	18	20	22	13
TSS in Settled Sludge from Drains (mg/ℓ)	8	--	35	80		

(continued on next page)

TABLE 1.(continued)

Parameter mg/ℓ	No. of Samples	Pond Influent	Pond Effluent No. 1 cov'd	Pond Effluent No. 2	% Removal No. 1 cov'd	% Removal No. 2
		24-hr Detention 10/31/73 - 12/24/73				
BOD	12	11	10	9	9	18
TOC	13	25	22	21	12	16
TSS	13	38	30	31	21	18
TVSS	9	20	15	16	25	20
NO_2-N + NO_3-N	9	2.3	1.0	0.7	57	70
NH_4-N	13	21.8	23.3	23.4	(7)	(7)
Total PO_4-P	13	2.6	1.8	1.8	31	31
Filtered PO_4-P	13	0.6	0.4	0.3	33	50
Turbidity (JTU)	13	17	13	12	24	29
		30-hr Detention 9/13/73 - 10/4/73				
BOD	7	19	15	20	21	(5)
TOC	8	35	30	35	14	0
TSS	8	55	35	56	36	(2)
TVSS	5	35	25	32	29	9
NO_2-N + NO_3-N	8	1.9	0.8	0.9	58	53
NH_4-N	8	26.3	28.6	28.4	(9)	(8)
Total PO_4-P	8	5.5	4.3	5.2	22	5
Filtered PO_4-P	8	--	1.0	0.9	--	--
Turbidity (JTU)	7	24	20	36	17	(50)

GRANULAR MEDIA FILTERS

Downflow Media A vs. Downflow Media B

The first phase of experiments with the pilot filters was designed to compare the two filters in a downflow mode of operation with a different filter media configuration in each unit. Specific information concerning the media configurations and other important parameters are shown in Figure 7 under the label, 1st Series of Tests. Media configurations for subsequent test series are also given in this figure. Filter No. 1 was a typical dual media unit as commonly used in water treatment with 56 cm (22 in.) of anthracite over 25 cm (10 in.) of sand (Media A). Filter No. 2 was a four media unit composed of 15 cm (6 in.) of fine anthracite over 36 cm (14 in.) of coarse anthracite over 15 cm (6 in.) of sand over 15 cm (6 in.) of fine garnet (Media B). The general idea in both filters was to obtain, to the extent possible, a decreasing particle interstitial space with increasing depth in the filter. In theory, this should allow all levels of the filter to function in the removal of solids. It had been suggested that the four media unit would be more effective as it more closely approached the desired geometry. The total depth of filter media in each unit was 81 cm (32 in.). The 5 cm (2 in.) of coarse garnet in the bottom of each unit served only for support of the media.

The downflow filters were operated at filtration rates varying from 1.0 to 2.7 $\ell/sec/m^2$ (1.5 to 4.0 gpm/ft^2) during the period from September 9, 1973, through April 4, 1974. The daily data collected are displayed in Table 2. Summary results are presented in Table 3 for each of the four filtration rates employed.

TSS removals generally ranged from 65 to 80 percent except for the lowest filtration rate, 1.0 $\ell/sec/m^2$ (1.5 gpm/ft^2), evaluated. At this rate, TSS removals of only 55 to 60 percent were achieved. Absolute effluent quality in terms of suspended solids and total phosphorus, but not BOD, was also poorer. This anomalous performance at the filtration rate where the best effluent quality would normally be expected cannot be explained by the author.

The rate of headloss buildup at filtration rates of 1.0, 1.4, and 2.0 $\ell/sec/m^2$ (1.5, 2.0, and 3.0 gpm/ft^2) seemed not to be affected by filtration rate. It should not, however, be concluded that headloss buildup and filtration rate are unrelated; in this investigation, the normally expected direct relationship of the two rates is obscured by the effect of variable quality filter influent on the rate of headloss buildup.

There was very little difference in the performance of the two downflow filters. For this reason, the simpler, more economical type, i.e., the dual

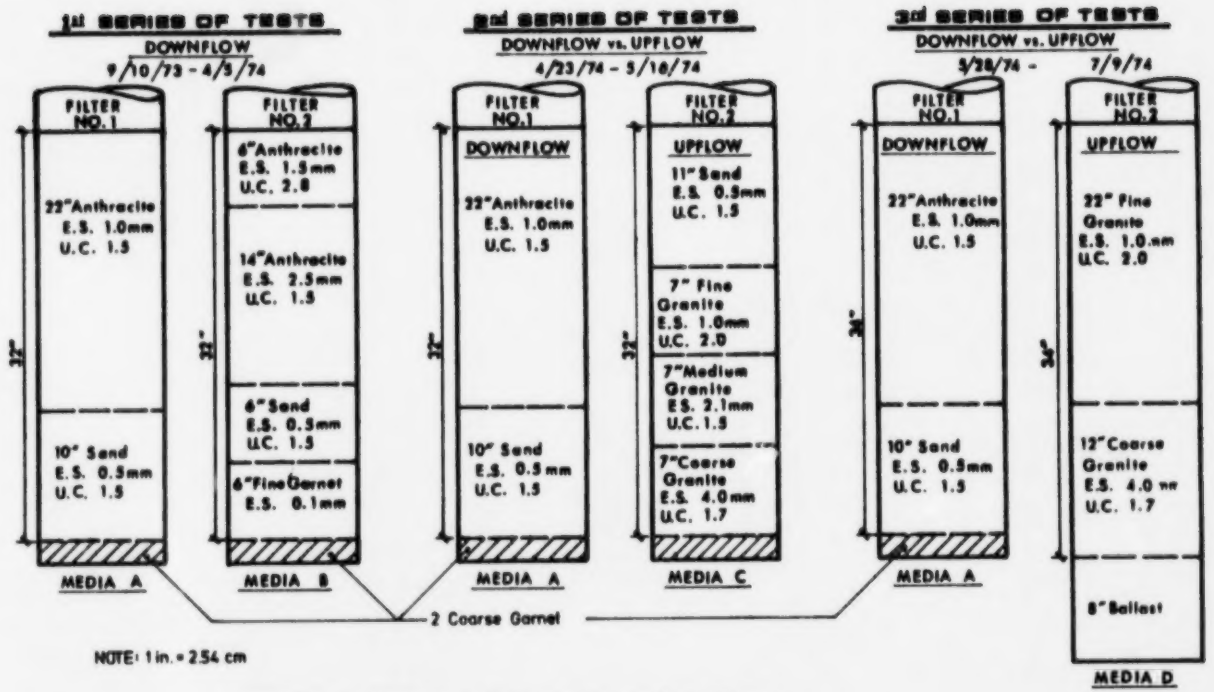

FIGURE 7. Granular filter media configurations.

TABLE 2. DAILY DATA – DOWNFLOW MEDIA A vs. DOWNFLOW MEDIA B

DATE	PLANT OPERATION: PLANT CLAR. LOADING (GPD/FT²)	PLANT OPERATION: PLANT ALUM DOSAGE (mg/l)	PLANT FINAL CLARIFIER EFFLUENT (FILTER INFLUENT QUALITY): BOD₅ (mg/l)	TOC (mg/l)	TSS (mg/l)	VSS (mg/l)	NH₃-N (mg/l)	PHOSPHORUS P: TOT (mg/l)	PHOSPHORUS P: SOL (mg/l)	TURB (JTU)	FILTER NO. 1 — 2.0 GPM/FT²: DOWNFLOW: MEDIA - A: OPERATING PARAMETERS: LENGTH OF RUN (HRS)	HEADLOSS (INCHES)	RATE OF HEADLOSS (IN./HR.)	FILTER EFFLUENT QUALITY: BOD₅ (mg/l)	TOC (mg/l)	TSS (mg/l)	VSS (mg/l)	PHOSPHORUS P: TOT (mg/l)	PHOSPHORUS P: SOL (mg/l)	TURB (JTU)	FILTER NO. 2 — 2.0 GPM/FT²: DOWNFLOW: MEDIA - B: OPERATING PARAMETERS: LENGTH OF RUN (HRS)	HEADLOSS (INCHES)	RATE OF HEADLOSS (IN./HR.)	FILTER EFFLUENT QUALITY: BOD₅ (mg/l)	TOC (mg/l)	TSS (mg/l)	VSS (mg/l)	PHOSPHORUS P: TOT (mg/l)	PHOSPHORUS P: SOL (mg/l)	TURB (JTU)
9-10-73	928	192	10	37	62	37	28	4.5	---	27	7	73	10.4	--	24	43	--	---	---	--	7	90	12.8	--	17	10	--	---	---	--
9-11-73	802	223	32	14	67	47	31	5.8	---	32	6	80	13.3	--	28	27	--	---	---	--	6	80	13.3	--	26	21	--	---	---	--
9-12-73	953	187	20	38	69	36	26	4.8	---	23	8	77	9.6	--	24	3	--	---	---	--	8	68	8.5	--	27	19	--	---	---	--
9-17-73	612	205	14	43	115	72	31	5.9	---	27	6	37	6.2	--	34	36	--	3.7	1.2	15	6	43	7.2	--	27	22	--	2.8	1.1	13
9-19-73	940	190	27	34	81	51	31	6.5	---	30	6	72	12.0	4	17	16	14	1.5	0.7	--	6	66	11.0	5	15	10	8	1.4	0.5	--
9-21-73	969	211	N/D	N/D	N/D	--	--	---	---	--	7	70	10.0	--	--	14	--	---	---	9	7	83	11.9	--	--	11	--	---	---	8
9-23-73	818	N/D	42	59	88	75	30	12.0	---	42	5	54	10.8	5	--	--	--	2.2	0.3	--	5	49	9.8	8	--	--	--	1.3	0.6	--
10-2-73	652	222	14	26	38	--	25	4.2	---	18	5	23	4.6	10	18	22	--	1.6	0.8	10	5	47	9.4	11	21	19	--	1.8	0.4	8
10-3-73	656	221	12	29	22	--	25	4.2	---	21	8	67	8.4	7	21	13	--	2.5	1.1	13	8	81	10.1	7	21	9	--	2.4	1.1	11
10-4-73	650	223	--	25	34	--	27	5.8	---	18	3	45	15.0	--	26	20	--	2.0	0.6	8	3	69	23.0	--	23	20	--	2.2	0.6	8
12-7-73	505	232	--	--	--	--	--	---	---	--	-	--	-----	--	--	--	--	---	---	--	-	--	-----	--	--	--	--	---	---	--
12-9-73	522	225	--	30	42	18	21	2.4	---	16	3	17	5.7	--	19	30	11	0.7	0.2	6	3	19	6.3	--	23	10	4	0.9	0.3	5
12-10-73	511	230	--	27	42	17	24	3.1	---	20	8	48	6.0	--	17	9	7	1.3	0.5	8	8	66	8.2	--	17	14	8	1.3	0.5	7
12-11-73	525	223	2	16	18	11	25	1.1	---	9	14	42	3.0	1	14	1	1	0.4	0.3	3	14	51	3.6	1	14	1	1	0.3	0.3	3
12-12-73	536	219	4	19	34	16	24	1.3	---	14	8	24	3.0	1	10	4	1	0.5	0.3	3	8	19	2.4	1	10	2	1	0.5	0.3	5
12-13-73	239	419	--	27	36	24	26	1.1	---	15	8	28	3.5	--	19	9	5	0.3	0.2	2	8	34	4.2	--	20	1	1	0.4	0.1	3
12-17-73	508	231	11	15	26	16	19	1.2	---	10	13	42	3.2	2	11	2	1	0.4	0.3	1	13	42	3.2	1	12	3	2	---	---	2
12-18-73	517	227	2	17	19	6	19	1.2	---	9	12	59	4.9	5	11	1	1	0.3	0.2	1	12	36	3.0	3	11	2	1	0.3	0.2	2
12-19-73	459	256	--	17	24	14	16	0.9	---	12	8.5	21	2.5	--	9	6	4	0.4	0.3	3	8.5	26	3.0	--	10	3	2	0.2	0.1	3
													3.0 GPM/FT² DOWNFLOW MEDIA - A										3.0 GPM/FT² DOWNFLOW MEDIA B								
1-2-74	470	249	1	9	26	13	11	2.2	0 8	13	7	21	3.0	1	4	8	7	2.6	1.2	4	7	22	3.1	1	3	2	2	1.1	---	3
1-3-74	472	248	2	13	23	13	11	1.8	0.9	19	21	66	3.1	1	10	4	2	2.2	0.5	6	21	68	3.2	1	9	9	5	3.2	0.4	6
1-7-74	560	209	--	13	19	8	17	1.0	0.2	7	10	29	2.9	1	9	3	1	0.2	0.2	3	10	35	3.5	1	13	2	1	0.2	0.2	3
1-8-74	557	211	1	16	20	10	19	1.2	0.8	9	4	13	3.2	1	12	4	2	0.4	0.3	3	4	8	2.0	1	15	3	1	0.2	0.2	3
1-9-74	653	180	7	17	33	13	20	1.9	0.5	14	4	10	2.5	6	12	6	3	0.5	0.4	6	4	12	3.0	12	12	7	3	0.5	0.4	3
1-10-74	624	188	7	19	31	16	20	1.6	0.5	14	9	48	5.3	2	12	3	2	0.6	0.5	6	9	47	5.2	2	13	1	1	0.5	0.4	5
1-15-74	555	211	--	22	50	25	26	2.3	0.4	23	6	72	12.0	11	14	10	5	0.3	0.3	5	6	29	4.8	3	15	5	3	0.4	0.2	5
1-16-74	557	211	14	27	32	11	26	2.0	0.2	14	5	21	4.2	8	18	24	14	0.4	0.1	4	5	25	5.0	5	17	9	5	0.4	0.1	3
1-17-74	563	---	17	32	48	--	28	3.0	0.2	21	7	70	10.0	5	16	9	--	0.9	0.2	6	7	75	10.7	8	23	7	--	0.8	0.1	4
1-22-74	594	197	12	27	33	--	25	1.2	0.2	11	10	79	7.9	5	17	12	--	0.4	0.2	5	10	90	9.0	4	18	11	--	0.7	0.1	3
1-28-74	827	142	14	33	33	18	25	2.5	0.4	17	10	73	7.3	4	25	8	5	1.2	0.2	7	10	90	9.0	7	25	11	8	1.0	0.2	7
1-29-74	777	151	--	29	33	21	19	1.5	0.1	17	8	53	6.6	--	22	9	4	0.5	0.2	5	8	70	8.7	--	17	10	4	0.6	0.2	5
1-30-74	346	339	3	19	21	19	19	0.7	0.1	8	24	71	2.9	2	14	6	3	0.4	0.1	3	24	83	3.5	3	11	6	3	0.3	0.1	3
1-31-74	310	378	2	12	25	21	20	0.6	0.1	2	24	33	1.4	1	8	7	4	0.1	0.1	4	24	50	2.1	2	8	4	2	0.1	0.1	5
2-1-74	508	231	--	--	--	--	--	---	---	--	8	15	1.9	--	--	--	--	---	---	--	8	20	2.5	--	--	--	--	---	---	--

(continued on next page)

TABLE 2. (continued)

DATE	PLANT OPERATION: PLANT CLAR. LOADING (GPD/FT²)	PLANT OPERATION: PLANT ALUM DOSAGE (mg/l)	PLANT FINAL CLARIFIER EFFLUENT (FILTER INFLUENT QUALITY): BOD5 (mg/l)	TOC (mg/l)	TSS (mg/l)	VSS (mg/l)	N (mg/l)	PHOSPHORUS P: TOT (mg/l)	PHOSPHORUS P: SOL (mg/l)	TURB (JTU)	FILTER NO. 1 — 4.0 GPM/FT² DOWNFLOW · MEDIA · A: OPERATING PARAMETERS: LENGTH OF RUN (HRS)	HEADLOSS (INCHES)	RATE OF HEADLOSS (IN./HR.)	FILTER EFFLUENT QUALITY: BOD5 (mg/l)	TOC (mg/l)	TSS (mg/l)	VSS (mg/l)	PHOSPHORUS P: TOT (mg/l)	PHOSPHORUS P: SOL (mg/l)	TURB (JTU)	FILTER NO. 2 — 4.0 GPM/FT² DOWNFLOW · MEDIA · B: OPERATING PARAMETERS: LENGTH OF RUN (HRS)	HEADLOSS (INCHES)	RATE OF HEADLOSS (IN./HR.)	FILTER EFFLUENT QUALITY: BOD5 (mg/l)	TOC (mg/l)	TSS (mg/l)	VSS (mg/l)	PHOSPHORUS P: TOT (mg/l)	PHOSPHORUS P: SOL (mg/l)	TURB (JTU)
2-11-74	618	190	16	27	29	11	21	2.1	0.2	13	7	56	8.0	5	21	1	1	0.5	0.2	3	7	71	10.1	5	18	1	1	0.5	0.2	3
2-12-74	604	194	16	29	42	19	25	2.6	0.3	16	8	65	8.1	5	21	7	3	0.7	0.2	4	8	80	10.1	6	19	5	3	0.7	0.3	3
2-13-74	597	196	16	25	34	15	26	2.4	0.3	14	7	64	9.1	7	16	12	8	0.7	0.3	4	7	80	11.4	7	17	10	5	0.7	0.1	4
2-14-74	586	200	13	33	25	13	26	1.8	0.3	13	7	58	8.3	4	17	8	4	0.6	0.2	4	7	71	10.1	5	19	4	2	0.9	0.3	4
2-15/17	1102	99	24	25	33	13	29	1.6	0.2	12	6	69	11.5	17	20	12	5	0.8	0.2	4	6	85	14.2	7	22	22	11	0.8	0.2	5
2-19-74	708	166	27	37	47	17	25	4.2	0.4	22	6	61	10.2	11	28	14	7	1.8	0.5	10	6	70	11.7	30	25	19	7	2.0	0.4	9
2-20-74	657	178	32	N/D	73	42	28	5.3	N/D	N/D	6	55	9.2	10	N/D	18	12	2.2	N/D	N/D	6	69	11.5	13	N/D	17	11	2.4	N/D	N/D
2-25-74	637	186	62	39	53	29	28	4.2	0.9	22	7	56	8.0	4	28	45	24	1.9	0.4	10	7	85	12.1	1	27	31	13	1.7	0.5	9
2-26-74	615	191	24	20	48	21	26	1.0	0.2	8	9	32	3.6	2	16	11	5	0.3	0.4	5	9	45	5.0	2	15	8	3	0.3	0.1	5
2-27-74	564	208	8	24	20	10	28	1.0	0.2	13	9	52	5.8	1	14	1	1	0.3	0.3	5	9	47	5.2	5	13	1	1	0.2	0.1	5
2-28-74	586	200	N/D	27	24	12	30	1.0	0.2	12	6	57	9.6	N/D	18	9	5	0.6	0.2	9	6	74	12.3	N/D	20	9	4	0.7	0.2	8
3-1/3-74	1627	72	8	22	27	16	25	2.1	0.6	15	6	61	10.2	4	16	3	2	0.6	0.1	6	6	76	12.8	4	16	3	2	0.4	0.2	3
3-4-74	555	211	N/D	25	33	20	31	1.5	0.1	13	5	53	10.6	7	16	6	4	0.6	0.1	4	5	72	14.4	4	18	6	6	0.4	0.1	5
3-5-74	572	205	27	19	40	14	25	2.1	0.1	14	6	67	11.2	19	16	17	8	1.0	0.4	7	6	88	14.7	27	23	16	8	0.8	0.2	7
3-6-74	580	170	16	27	36	19	28	1.9	0.1	13	6	73	12.2	3	20	19	9	2.6	0.1	5	6	84	14.0	3	22	10	9	1.3	0.1	4
3-7-74	572	172	N/D	32	53	33	27	3.2	0.5	19	8	81	10.1	N/D	26	26	25	2.0	1.4	12	8	94	11.8	N/D	26	24	20	2.0	2.0	12
3-11-74	430	229	4	17	15	7	22	1.1	0.3	8	8	46	5.8	2	13	3	1	0.4	0.2	3	8	59	7.4	1	13	4	3	0.4	0.3	3
3-12-74	440	224	18	24	42	37	22	1.6	0.2	14	6	57	9.6	4	16	17	13	0.5	0.4	7	6	67	11.2	2	16	11	10	0.8	0.1	5
3-13-74	436	226	N/D	23	33	31	20	2.4	0.2	15	7	66	9.4	--	16	7	2	0.9	0.3	6	7	91	13.0	--	16	8	4	0.9	0.1	7
3-20-74	---	---	N/D	--	--	--	--	---	---	--	6	45	7.5	--	--	--	--	---	---	--	6	59	9.8	--	--	--	--	---	---	--
3-21-74	---	---	40	36	39	--	29	3.9	0.7	24	6	57	9.5	10	28	11	--	2.7	0.8	14	6	74	12.3	11	29	13	--	2.8	0.7	13
											1.5 GPM/FT² DOWNFLOW · MEDIA · A										1.5 GPM/FT² DOWNFLOW · MEDIA · B									
3-25-74	597	165	N/D	33	42	--	28	4.0	0.8	20	7	24	3.4	--	23	20	--	3.3	0.7	12	7	33	4.7	--	23	19	--	3.2	0.7	11
3-26-74	2472	40	N/D	35	54	--	28	4.5	0.5	21	5	11	2.2	--	21	19	--	2.2	0.5	8	5	18	3.6	--	22	18	--	2.9	0.5	10
4-1-74	572	---	N/D	43	28	--	22	5.0	0.7	--	7	11	1.6	--	28	21	--	2.8	0.5	--	7	23	3.3	--	29	19	--	3.0	0.5	--
4-2-74	630	156	41	32	41	--	22	4.1	0.7	17	8	14	1.7	10	21	9	--	2.5	0.4	9	8	30	3.8	13	20	19	--	2.4	0.4	9
4-3-74	580	170	8	32	41	--	24	3.6	0.5	17	9	27	3.0	4	21	19	--	1.9	0.5	9	9	39	4.3	2	20	17	--	1.9	0.4	9
4-4-74	616	160	18	25	29	20	22	2.2	0.4	14	8	21	*2.6	2	20	12	11	1.5	0.4	7	8	30	3.7	2	20	11	10	1.5	0.7	7
4-5-74	632	156	6	34	33	14	20	3.1	0.5	18	8	17	2.5	3	20	13	9	2.2	0.5	12	8	33	4.1	1	20	16	16	2.0	0.3	10

NOTE: 1 in = 2.54 cm
1 gpm/ft² = 0.679 l/sec/m²

TABLE 3. SUMMARY RESULTS - DOWNFLOW MEDIA A VS. DOWNFLOW MEDIA B

1.5 gpm/ft^2	Influent mg/ℓ	Effluent Downflow Media A mg/ℓ	% removal	Effluent Downflow Media B mg/ℓ	% removal
BOD	18	5	72	5	72
TSS	38	16	58	17	55
Total PO_4-P	3.8	2.3	39	2.4	37
Rate of Headloss Buildup (in./hr)		2.4		3.9	
2.0 gpm/ft^2					
BOD	16	4	75	5	69
TSS	48	15	69	10	79
Total PO_4-P	3.9	1.3	67	1.2	69
Rate of Headloss Buildup (in./hr)		7.6		8.4	
3.0 gpm/ft^2					
BOD	7	4	43	5	29
TSS	31	8	74	6	81
Total PO_4-P	1.7	0.8	53	0.2	88
Rate of Headloss Buildup (in./hr)		5.0		5.0	
4.0 gpm/ft^2					
BOD	22	7	68	8	64
TSS	34	12	65	11	68
Total PO_4-P	2.4	1.1	54	1.0	58
Rate of Headloss Buildup (in./hr)		8.9		11.2	

Notes: 1 in = 2.54 cm
1 gpm/ft^2 = 0.679 ℓ/sec/m^2

media filter (Media A), was chosen for further evaluation in comparison with upflow models.

Downflow Media A vs. Upflow Media C

The first upflow media configuration was constructed in Filter No. 2 as shown previously in Figure 7 (2nd Series of Tests, Filter No. 2,Media C). This filter and dual media Filter No. 1 (Media A) were operated in parallel at a filtration rate of 1.4 $\ell/sec/m^2$ (2.0 gpm/ft^2) during the period from April 23, 1974,through May 16, 1974. Daily data collected during this phase are presented in Table 4.

The first upflow filter did not function well. As headloss built up in the upper layers of the sand media, a point was reached at which the immersed weight of an overlying layer of sand was equal or less than the headloss through that layer. The overlying layer then lifted as a unit, separating from the lower layers. Somewhat later, the upper, separated layer would collapse. This would result in a major breakthrough of previously removed particulate matter. This situation was controlled by the installation of a removable grid in the upper layers of the upflow media. The grid seemed to retard, but did not entirely prevent, media separation. Because of this problem, work with Media C was stopped and a modified upflow filter (Media D) was constructed.

The air scour was found to be essential for properly backwashing the upflow filters. Because of the direction of flow, the lower layers of the filter accumulated a much heavier solids deposit than did the upper layers. Also, the coarse granite media in the bottom of the upflow filters could be moved, but not actually suspended, with the quantity of backwash water available. As a result, some of the deposited materials tended to cling to the media unless air scour was applied prior to the water wash. Air scour was applied for approximately 2 min along with a small flow of backwash water. Following this, the air was turned off and a normal amount of backwash water was applied for 8 to 10 min. This procedure effectively cleaned all upflow filter media used. In downflow filtration, it was found that the occasional use of air scour prevented the formation of mud (sludge) balls.

Downflow Media A performed slightly better than upflow Media C with regard to effluent quality. However, the rate of headloss buildup in the upflow filter was only 42 percent of that in the downflow model. This indicates that much longer filter runs might have been possible before backwash was necessary. Because of the problem of bed separation experienced with upflow Media C, it was not possible to operate this upflow filter configuration for extended periods to demonstrate its full economic potential.

Pertinent summary results observed during experiments with downflow Media A and upflow Media C are presented in Table 5. TSS removal averaged approximately 75 percent for both units.

TABLE 4. DAILY DATA – DOWNFLOW MEDIA A vs. UPFLOW MEDIA C

DATE	PLANT OPERATION		PLANT FINAL CLARIFIER EFFLUENT (FILTER INFLUENT QUALITY)								FILTER NO. 1 — 2.0 GPM/FT²: DOWNFLOW: MEDIA: A										FILTER NO. 2 — 2.0 GPM/FT²: UPFLOW: MEDIA: C									
											OPERATING PARAMETERS			FILTER EFFLUENT QUALITY							OPERATING PARAMETERS			FILTER EFFLUENT QUALITY						
	PLANT CLAR LOADING (GPD/FT²)	PLANT ALUM DOSAGE (mg/l)	BOD_5 (mg/l)	TOC (mg/l)	TSS (mg/l)	VSS (mg/l)	N (mg/l)	PHOSPHORUS-P TOT (mg/l)	PHOSPHORUS-P SOL (mg/l)	TURB (JTU)	LENGTH OF RUN (HRS)	HEADLOSS (INCHES)	RATE OF HEADLOSS (IN./HR.)	BOD_5 (mg/l)	TOC (mg/l)	TSS (mg/l)	VSS (mg/l)	PHOSPHORUS-P TOT (mg/l)	PHOSPHORUS-P SOL (mg/l)	TURB (JTU)	LENGTH OF RUN (HRS)	HEADLOSS (INCHES)	RATE OF HEADLOSS (IN./HR.)	BOD_5 (mg/l)	TOC (mg/l)	TSS (mg/l)	VSS (mg/l)	PHOSPHORUS-P TOT (mg/l)	PHOSPHORUS-P SOL (mg/l)	TURB (JTU)
4-23-74	1041	186	---	36	52	32	29	4.2	0.7	18	6	27	4.5	---	23	19	10	1.9	0.5	2.3	6	14	2.3	---	23	19	17	1.8	0.6	7
4-26-74	988	196	---	--	--	--	--	---	---	--	5	18	3.6	---	--	--	--	---	---	---	5	13	2.6	---	--	--	--	---	---	-
4-29-74	1006	192	---	35	38	35	23	0.5	0.3	11	8	73	9.1	---	27	8	--	0.5	0.3	1.1	8	19	2.4	---	28	13	12	0.4	0.3	6
4-30-74	1019	190	13	19	56	44	26	1.5	0.3	10	8	46	5.7	1	11	16	11	0.7	0.3	0.8	8	18	2.2	5	11	16	15	0.7	0.5	3
5-1-74	1006	192	13	22	72	59	24	1.7	--	9	7	28	4.0	6	14	10	3	0.6	0.5	1.2	7	12	1.7	3	14	10	8	0.7	0.5	3
5-2-74	1107	175	---	26	93	49	24	2.7	0.1	20	7	81	11.6	---	16	24	12	1.8	0.4	1.9	7	14	2.0	---	11	30	25	1.8	0.4	10
5-5-74	1063	182	---	12	41	33	18	1.1	0.3	10	8	21	2.9	---	5	5	3	0.5	0.3	0.3	8	10	1.3	---	5	4	2	0.4	0.3	2
5-6-74	1129	171	---	18	50	43	20	1.9	0.3	17	6	32	5.3	---	9	13	7	0.5	0.2	3.1	6	19	3.2	---	9	12	8	0.4	0.3	4
5-7-74	959	201	23	19	33	12	23	2.1	0.6	18	7	32	4.6	5	7	11	9	0.5	0.3	1.1	7	14	2.0	18	8	8	7	0.4	0.3	5
5-13-74	1324	---	30	4	41	22	11	2.0	0.4	13	8	22	2.7	4	1	7	5	0.3	0.2	---	8	25	3.1	---	--	--	--	---	---	-
5-14-74	1076	180	13	6	31	23	14	1.5	0.3	13	9	25	2.8	3	2	6	5	0.3	0.2	---	9	23	2.6	6	6	14	8	0.2	0.2	8
5-15-74	978	198	8	10	45	28	16	0.7	---	--	9	71	7.9	---	--	--	--	---	---	---	10	18	1.8	6	3	12	11	0.2	0.2	-
5-16-74	969	199	11	6	32	20	15	1.4	---	--	8	24	3.0	5	2	12	8	0.3	0.1	0.3	8	17	2.1	3	4	8	6	0.2	0.2	-

NOTES: 1 in = 2.54 cm
1 gpm/ft² = 0.679 l/sec/m²

TABLE 5. SUMMARY RESULTS - DOWNFLOW MEDIA A VS. UPFLOW MEDIA C

2.0 gpm/ft^2	Influent	Effluent			
		Downflow Media A		Upflow Media C	
	mg/ℓ	mg/ℓ	% removal	mg/ℓ	% removal
BOD	16	4	75	7	56
TSS	49	12	76	13	73
Total PO_4-P	1.8	0.7	61	0.7	61
Rate of Headloss Buildup (in./hr)		5.2		2.2	

Notes: 1 in. = 2.54 cm
1 gpm/ft^2 = 0.679 ℓ/sec/m^2

Downflow Media A vs. Upflow Media D

The third series of filtration experiments was conducted with the same dual media downflow filter (Media A) previously described and a modified upflow filter (Media D). No sand was used in this upflow model. The filter consisted of 56 cm (22 in.) of fine granite chips, 30 cm (12 in.) of coarse granite chips, and 20 cm (8 in.) of ballast stone about 2½ cm (1 in.) in nominal size. This media configuration was previously illustrated in Figure 7 under the heading, 3rd Series of Tests, Filter No. 2, Media D. The dual media downflow and modified upflow filters were operated at filtration rates of 1.4 and 2.0 ℓ/sec/m^2 (2.0 and 3.0 gpm/ft^2) during the period from May 28, 1974 through July 9, 1974. The daily data collected are displayed in Table 6.

Modified upflow Media D eliminated the layer separation problem, and no hold-down grid was required.

The upflow Media D filter composed entirely of granite chips performed well. The rate of headloss buildup was 63 percent less than that of the downflow Media A filter. Although the average upflow filter effluent quality as summarized in Table 7 was slightly poorer, much longer filter runs were possible. When personnel were available for round-the-clock operation, the upflow filter runs ranged from 21 to 27 hr. Downflow filter runs on these dates ranged from 7 to 10 hr. TSS removals during this series of runs ranged from 70 to 90 percent, the highest percentage levels achieved throughout the filtration experiments.

The upflow Media D filter should be more economical to operate at plant scale as it would require much less frequent backwashing. In addition, the filter media itself is readily available at farm supply wholesalers. The media was purchased as "chicken grit" in 22.7-kg (50-lb) bags from a local farm supply store. The material is closely graded and when purchased in

TABLE 8. DAILY DATA–DOWNFLOW MEDIA A vs. UPFLOW MEDIA D

DATE	PLANT OPERATION: PLANT CLAR LOADING (GPD/FT²)	PLANT OPERATION: PLANT ALUM DOSAGE (mg/l)	PLANT FINAL CLARIFIER EFFLUENT (FILTER INFLUENT QUALITY): BOD_5 (mg/l)	TOC (mg/l)	TSS (mg/l)	VSS (mg/l)	NH_3-N (mg/l)	PHOSPHORUS-P: TOT (mg/l)	PHOSPHORUS-P: SOL (mg/l)	TURB (JTU)	FILTER NO. 1 — 2.0 GPM/FT² : DOWNFLOW : MEDIA : A — OPERATING PARAMETERS: LENGTH OF RUN (HRS.)	HEADLOSS (INCHES)	RATE OF HEADLOSS (IN./HR.)	FILTER EFFLUENT QUALITY: BOD_5 (mg/l)	TOC (mg/l)	TSS (mg/l)	VSS (mg/l)	PHOSPHORUS-P: TOT (mg/l)	PHOSPHORUS-P: SOL (mg/l)	TURB (JTU)	FILTER NO. 2 — 2.0 GPM/FT² : UPFLOW : MEDIA : D — OPERATING PARAMETERS: LENGTH OF RUN (HRS.)	HEADLOSS (INCHES)	RATE OF HEADLOSS (IN./HR.)	FILTER EFFLUENT QUALITY: BOD_5 (mg/l)	TOC (mg/l)	TSS (mg/l)	VSS (mg/l)	PHOSPHORUS-P: TOT (mg/l)	PHOSPHORUS-P: SOL (mg/l)	TURB (JTU)
5-28-74	1107	175	13	20	47	39	17	1.5	0.2	23	8	15	1.9	4	13	24	20	0.3	0.2	0.3	5	3	1.7	12	11	16	15	0.3	0.2	4
5-29-74	1060	182	--	--	--	--	--	---	---	--	8	55	6.9	---	--	--	--	---	---	---	12	16	1.3	--	--	--	--	---	---	-
5-30-74	1025	188	16	22	29	17	23	2.7	0.4	13	10	46	4.6	8	12	5	3	0.4	0.1	1.0	24	54	2.2	9	21	4	1	0.6	0.2	4
6-3-74	1022	189	7	31	59	41	27	2.5	0.2	18	7	78	11.1	1	11	4	3	0.3	0.2	0.4	22	34	1.5	1	12	11	9	0.8	0.2	3
6-4-74	1013	191	18	29	7	3	19	3.4	0 2	18	8	25	3.1	3	15	17	11	0.3	0.2	5.9	27	27	1.0	10	21	17	12	0.9	0.2	4
6-6-74	1014	185	13	23	64	--	28	2.8	0.2	17	--	--	---	2	10	9	--	0.3	0.2	0.7	8	8	1.0	2	11	7	--	0.5	0.2	4
6-10-74	985	196	---	--	--	--	--	---	---	--	8	33	4.1	---	--	--	--	---	---	---	9	17	1.9	---	--	--	--	---	---	-
6-11-74	966	200	10	42	125	--	25	1.4	---	66	8	23	2.9	10	9	16	--	0.3	---	1.8	9	25	2.8	---	20	11	--	0.3	---	2
6-12-74	944	205	20	25	55	--	25	2.1	0.2	16	8	59	7.4	3	13	8	--	0.4	0.1	2.2	8	12	1.5	6	13	8	--	0.5	0.2	2
6-13-74	950	203	24	33	53	--	24	3.7	0.2	17	9	68	7.6	2	13	7	--	0.3	0.2	1.2	10	32	3.2	7	15	8	--	0.4	0.2	2
6-14-74	925	209	--	42	69	--	20	3.4	0.2	33	9	63	7.0	---	10	4	--	0.3	0.2	1.2	9	18	2.0	---	14	6	--	0.5	0.3	3
6-17-74	1022	189	15	29	67	--	20	2.7	0.2	18	7	30	4.3	1	12	10	--	0.4	0.3	2.0	7	8	1.1	1	15	11	--	0.3	0.2	2
6-18-74	969	199	26	27	57	33	17	3.3	0.4	29	7	23	3.3	1	10	4	2	0.2	0.2	1.2	21	60	2.9	3	12	4	2	0.2	0.2	1
6-19-74	---	---	47	54	76	46	20	6.0	0.5	61	8	34	4.2	2	11	5	3	0.2	0.2	0.7	8	13	1.6	5	16	6	4	0.2	0.2	2
6-20-74	985	196	16	33	57	54	18	2.0	0.3	19	-	--	---	---	--	--	--	---	---	---	21	29	1.4	2	20	8	7	0.3	0.3	4
6-21-74	906	213	100	22	28	21	24	2.1	0.4	13	7	36	5.1	2	10	4	3	0.4	0.5	3.0	7	8	1.1	1	11	6	5	0.4	0.4	3
											3.0 GPM/FT² : DOWNFLOW : MEDIA : A										3.0 GPM/FT² UPFLOW : MEDIA : D									
6-24-74	981	197	17	25	28	22	18	1.3	---	13	8	89	11.5	7	11	3	2	---	---	3	9	42	4.7	9	11	3	2	---	---	3
6-25-74	940	205	26	27	54	43	21	1.3	---	18	5	58	11.6	8	7	4	3	---	---	2	7	18	2.6	13	12	6	4	---	---	2
6-27-74	969	199	10	28	32	15	19	1.5	---	22	8	63	7.9	3	11	2	1	---	---	2	8	35	4.4	1	15	6	3	---	---	4
6-28-74	906	213	8	17	23	17	--	---	---	14	8	58	7.2	6	8	2	1	---	---	3	8	31	3.9	2	9	8	6	---	---	4
7-1-74	969	199	32	38	57	49	--	---	---	37	7	37	5.3	22	11	3	2	---	---	3	7	21	3.0	14	16	17	13	---	---	0
7-2-74	925	209	24	20	51	37	--	---	---	17	8	66	8.2	5	8	3	2	---	---	5	6	18	3.0	2	10	6	5	---	---	4
7-7-74	821	---	25	25	66	33	--	---	---	23	6	10	1.7	8	10	16	11	---	---	6	6	7	1.2	21	24	37	27	---	---	20
7-8-74	1019	190	31	27	55	32	--	---	---	17	7	51	7.3	16	15	10	6	---	---	3	7	18	2.6	7	16	17	17	---	---	5

NOTES: 1 in = 2.54 cm
1 gpm/ft = 0.679 l sec m

large quantities should cost much less than more conventional filter media.

TABLE 7. SUMMARY RESULTS - DOWNFLOW MEDIA A VS. UPFLOW MEDIA D

2.0 gpm/ft^2	Influent mg/ℓ	Effluent			
		Downflow Media A		Upflow Media D	
		mg/ℓ	% removal	mg/ℓ	% removal
BOD	25	3	88	5	80
TSS	57	9	84	9	84
Total PO_4-P	2.9	0.3	90	0.4	86
Rate of Headloss Buildup (in./hr)		5.3		1.8	
3.0 gpm/ft^2					
BOD	22	9	59	9	59
TSS	46	5	89	13	72
Total PO_4-P	1.4	-	--	-	--
Rate of Headloss Buildup (in./hr)		7.6		3.2	

Notes: 1 in. = 2.54 cm

1 gpm/ft^2 = 0.679 ℓ/sec/m^2

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